NORTHEASTERN FOREST EXPERIMENT STATION

Semiannual Report
Watershed Management Research

October 1, 1965 - March 31, 1966

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PROJECT 1601 - WATER YIELD IMPROVEMENT

First treatment at Hubbard Brook

At The Pennsylvania State University Forest Hydrology Symposium last August, Howard Lull succinctly described watershed research activities in the past--calibrate, clearcut, and publish. To this, someone added--apologize! After many discussions with persons who have experienced these three or four "axioms", we pondered the validity of following this well-worn path because three of our watersheds at Hubbard Brook were calibrated and presumably ready for the next critical step.

In spite of the apparent pitfalls associated with interpreting the effects of treated forested watersheds, a decision was reached to clearcut Watershed #2. The treatment on this 38.6 acre, south-facing watershed of northern hardwoods was patterned after the original Coweeta Watershed #17 experiment where all woody vegetation was felled and left in place. Logging was eliminated to prevent confounding treatment effects. The entire clearcut treatment was accomplished during the 1965-66 dormant season. Soil sterilants and herbicidal applications will be used to perpetuate a virtually transpiration-free watershed for several years.

The treatment has two purposes: (1) it should give us a bench mark value for maximum transpiration reduction, and (2) it should provide good information on snow accumulation and timing of snowmelt runoff.

We are not so naive to think this is a highly controlled experiment, but we do feel confident that within certain limitations much can be gained from the treatment. Our reasons for this are: (1) high correlations were found between the three watersheds for annual, seasonal, and other periodic intervals; (2) a wide range of climatic events (wet, dry and intermediate years) occurred within the six-year calibration; (3) tight bedrock is present with a sharp demarkation between bedrock and soil; and (4) two major conditions cited by Penman as being critical for the paired watershed approach are met--P-RO for each watershed is essentially the same, and P-RO is equal to or slightly less than potential evapotranspiration. In both of the latter cases, the difference is one inch or less.

The clearcutting treatment required about 4 man-days per acre at $4.00 per hour.

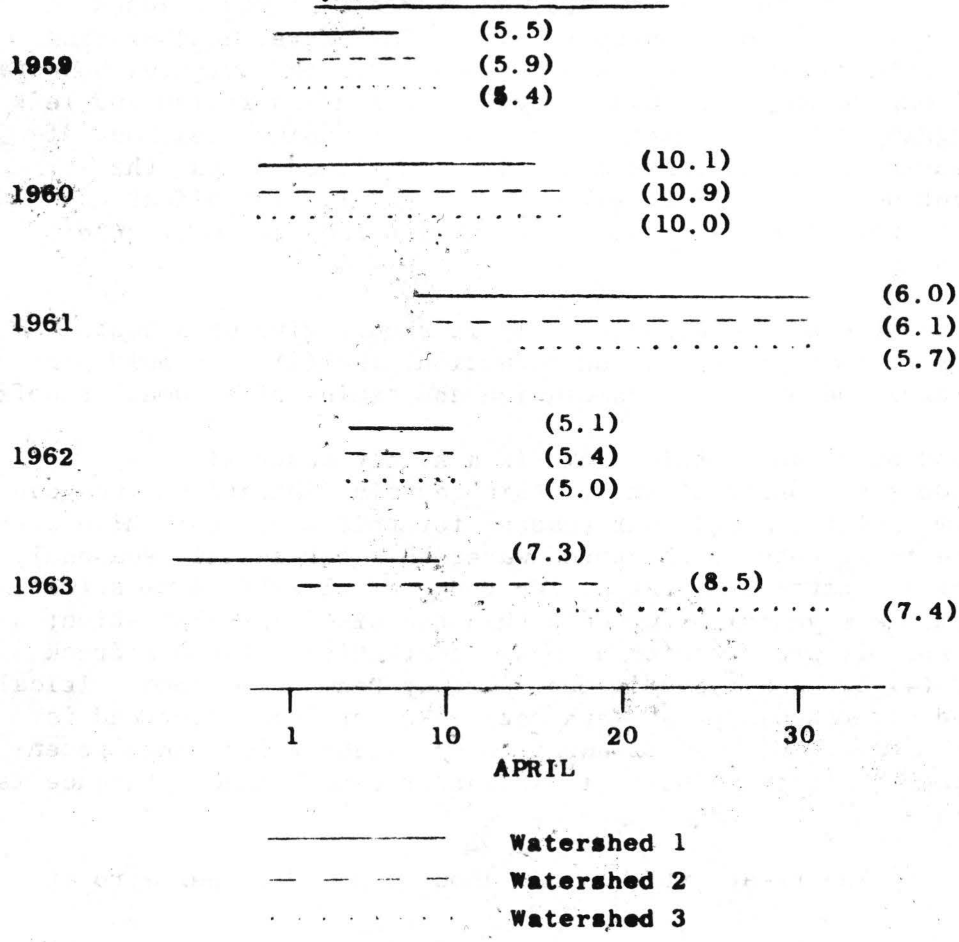
Flow interval

The flow interval concept, namely the shortest time required to pass a certain percentage of the annual flow, has been used successfully in the West as an index of snowmelt runoff timing. On three adjacent watersheds at the Hubbard Brook Experimental Forest, this method was unsuccessful. Because heavy runoff from autumn rains can obscure snowmelt timing with this concept in the East, the interval (one quarter of the annual flow) was restricted to March and April.

The length of the interval for five snowmelt seasons, together with the quarter-flow values, is shown in Figure 1. The average aspect of Watersheds 1, 2, and 3 are S22E, S31E, and S23W, respectively. Watersheds 1 and 2 both slope uniformly SSE; but nearly half of Watershed 3 faces almost due west and another portion faces east. This watershed is more shaded from mid-day solar radiation than are the other two watersheds, and a notable delay in the quarter-flow interval would be expected. But, as shown in Figure 1, this delay occurs only in 1963, and in all other years the intervals are almost simultaneous.

FIGURE 1

Quarter-flow Intervals



The synchronization of snowmelt runoff is attributed to substantial rainfall, amounting to as much as 1.5 inches per day, during the melt period. This serves to concentrate runoff into intervals which are nearly the same on all watersheds, regardless of aspect. In 1963 a 2-week rainfree period occurred and the differential timing of snowmelt was expressed.

Because of the masking effect of rain-on-snow during the melt period, we must seek other methods for evaluating snowmelt timing. For the present we are using frequent measurements on snow courses in our clearcut Watershed 2 as an index to snowmelt.

Potential evapotranspiration from solar radiation

In the process of testing several methods for keeping a daily water balance for Hubbard Brook watersheds in the summer, we have tried out a solar radiation method for estimating daily potential evapotranspiration. This has been compared with the Thornthwaite method, the only other PE estimate for which we have data, and which has already been shown to give a good estimate of annual P-RO (see Semiannual Report April - October 1965).

Our solar radiation data is from a battered-looking pyrheliograph which was calibrated against a Kipp in July and August 1965 yielding, in ly/day,

$$KIP = 1.016\ PYR + 10$$

$$n = 27 \quad Sy.x = 19 \quad r^2 = .98$$

A similar calibration of an instrument at Fernow gave

$$KIP = 0.891\ PYR + 21$$

$$n = 53 \quad Sy.x = 21 \quad r^2 = .98$$

The Fernow Kipp was equipped with a disc integrator; the Hubbard Brook Kipp was integrated by cutting and weighing the charts. The pyrheliographs in both cases used seven-day charts. These charts were integrated by eyeball averaging over two-hour intervals (i.e., between adjacent lines on the chart) to the nearest 0.05 ly/min. and using a nighttime zero correction to the nearest 0.01 ly/min. This method was fast and gave a standard error one-half of that obtained by planimeter integration. This standard error is low enough that the instrument may be relied on for daily integrals useful in watershed work. However, values obtained with separate instruments should be compared with caution, e.g., measuring radiation reception by various slopes and aspects.

Potential evapotranspiration has been estimated from the solar radiation using the following equation:

$$PE\ (\text{inches}) = 0.000673 \times f \times a \times i \times R\ (\text{ly})$$

where f is a constant, a is a seasonal correction, i is a slope and aspect correction and R is the solar radiation. The seasonal correction a, is 1.0 in the summer and 0.3 in the winter, with a linear decrease from September 15 to October 15 to correspond to our leafout and leaffall periods. The slope-aspect correction is unity for a horizontal surface and otherwise is (1 + bR) where

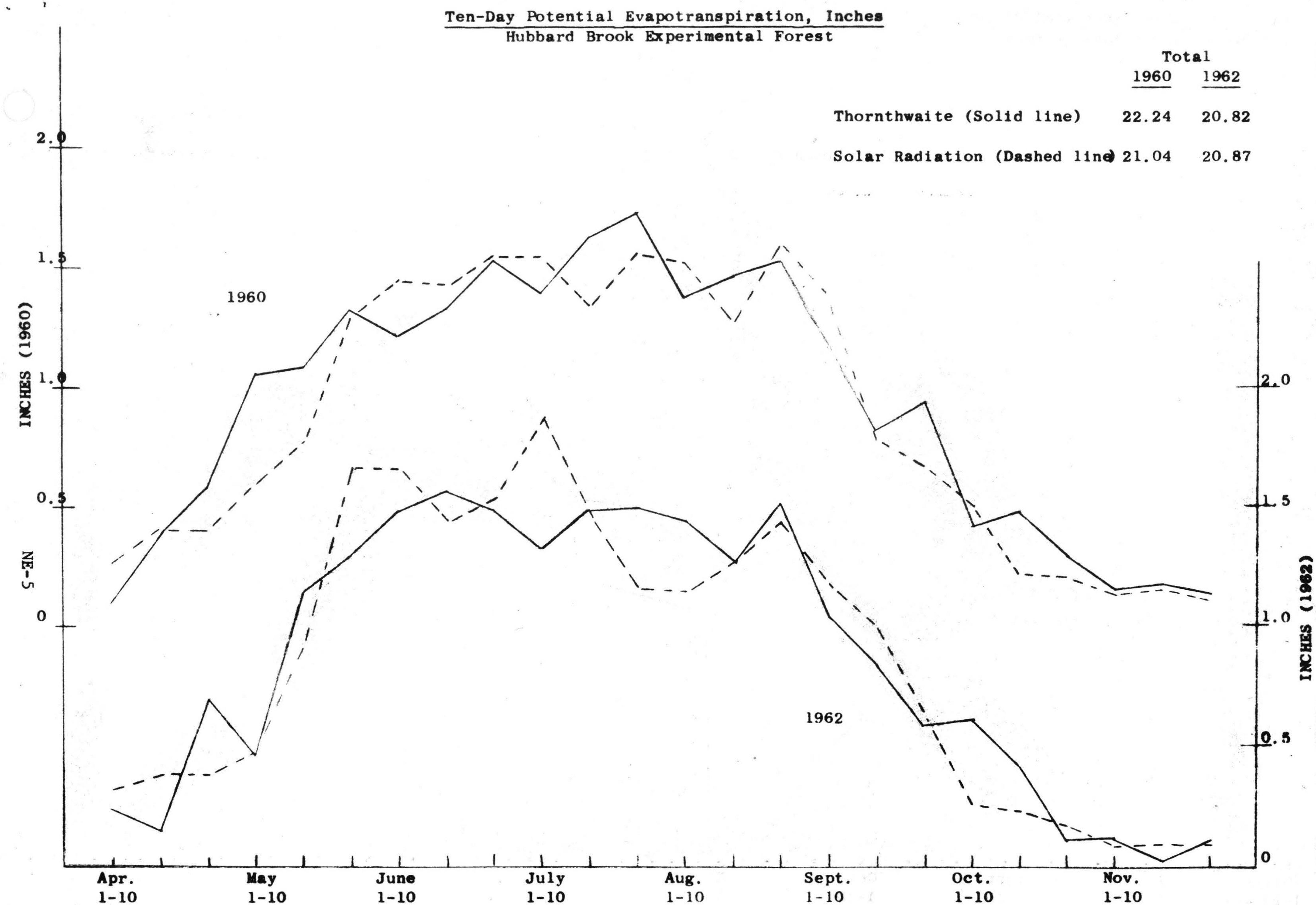
$$b = \frac{1}{R_{ph}} \left[\frac{R_{pw}}{R_{ph}} - 1\right]$$

with R_{ph} the potential insolation (no atmosphere) on a horizontal surface and R_{pw} the potential insolation on the lid of the watershed. The term b changes from month to month. This correction reduces itself as R/R_{ph} decreases, to allow for an increasing proportion of diffuse radiation, which requires no slope-aspect correction. The constant f is in one sense a conversion from incoming solar to net radiation, and in another sense a fudge factor as it can cover up systematic errors in R. We have used f = 0.45 for Hubbard Brook to give the best agreement with annual Thornthwaite PE.

On a daily basis for a given month the correlation between PE's from the Thornthwaite and the solar radiation is very poor (e.g., for July 1960 r = 0.17). Figure 2 shows what happens when ten-day averages are used. The solar radiation PE is for a horizontal surface (b = 0). The similarity of the two independent estimates is striking. It is obvious that for soil moisture accounting in which generally only changes over a period of a week or so can be detected, it is almost immaterial which PE estimate is used. On the other hand, if daily changes could be measured, the solar radiation method should follow them more closely.

--Bob Pierce
George Hart
Tony Federer

FIGURE 2



Ten-Day Potential Evapotranspiration, Inches
Hubbard Brook Experimental Forest
Total
1960
1962
Thornthwaite (Solid line) 22.24 20.82
Solar Radiation (Dashed line) 21.04 20.87
INCHES (1960)
2.0
1.5
1.0
0.5
0
1960
1962
INCHES (1962)
2.0
1.5
1.0
0.5
0
Apr. 1-10
May 1-10
June 1-10
July 1-10
Aug. 1-10
Sept. 1-10
Oct. 1-10
Nov. 1-10

PROJECT 1602 - FLOODS AND WATER YIELD

Half-cut watersheds

Streamflow increases following clearcutting and silviciding the lower half of Watershed 6 and upper half of Watershed 7 continue to be quite striking. Increases for the 1965 growing season (May-October) have been measured as follows:

Month	Upper 7	Lower 6
	Streamflow increase in thousands of gallons per treated acre	
May, 1965	8	0
June	13	27
July	59	43
August	21	18
September	24	27
October	59	39
Growing Season	184	154

These increases occurred despite the fact that 1965 growing-season precipitation was the lowest (18.67 vs. an average of 27.81 inches) since the start of record collection in 1951.

Foliage production measurements have shown that our aim of complete vegetation removal on the treated areas of the watersheds has been relatively successful. Based on data from milacre plots clipped in September, 1965, oven-dry weight of remaining live vegetation was estimated to be 62 pounds per treated acre. In contrast, leaf fall on the untreated halves of the watersheds averaged 2575 pounds, oven-dry weight, per acre. The reduction is almost 98 percent.

Checks on water quality are made at weekly intervals and during storm periods. The effectiveness of the careful logging practices used when half clearing the watersheds is demonstrated by the fact that the maximum turbidity following logging has been only 83 parts per million. This is in contrast to the maximum of 56,000 parts per million that followed the carelessly logged commercial clearcutting on Watershed 1 some years ago. This lends support to an earlier conclusion: it isn't how much you cut but how you conduct the operation.

Energy budget study

A study of the energy budget on the cleared and forested halves of Watershed 6 will get under way this May. An 80 ft. tower has been erected on each half to obtain climatic measurements necessary for computing the energy budget components. It is hoped that comparisons of energy budget components for the two sites will help explain post-treatment streamflow changes.

5 > 4 - Why?

One of the perplexities of our studies has been that despite the outward appearance of being very similar watersheds, annual flow from Watershed 5 has exceeded that from adjacent Watershed 4 by an average of 6.5 area inches during the 14 years of record. In a recent study, Lee[1/] theorized that streamflow differences between 4 and 5 can be explained by differences in potential irradiation (4 has a more southerly orientation and steeper slopes). His theory seems well founded and some follow-up calculations have been made.

Although Lee shows that streamflow and potential irradiation are closely related, he does not show whether energy differences between 4 and 5 are sufficiently large to evaporate the average difference in streamflow. Our computations of potential irradiation (based on Fernow pyrheliograph records) showed that irradiation of 4 exceeded 5 by 9900 gm cal/cm^2/year.

This poses the question: how much of this excess radiation is used in evapotranspiration. Calculations based on P - RO = ET indicated that 43 percent of the calculated annual irradiation on 4 is used for ET. If the excess radiation received by 4 is used in the same proportion, 43 percent of the excess will evaporate 2.8 of the 6.5 inches difference between watersheds (calculations are based on heat of vaporization of 1 inch of water = 1500 gm cal/cm^2). Thus it would seem that some factors (s) other than irradiation difference is responsible for most of the streamflow difference.

Miscellaneous

Chuck Troendle, a recent Syracuse graduate, joined our staff at the beginning of March. Chuck studied under former Fernowite Art Eschner and analyzed Fernow streamflow data in preparation for his Master's thesis.

Our neutron moisture meter has been returned to Troxler Laboratories for conversion from a 5 mc Radium-Berrylium to a 100 mc Americium-Berrylium source. A higher count rate and reduction in shield weight are the main reasons for switching.

Arthur Summerfield's prize heifer was killed when it fell out of the pasture onto a railroad right-of-way.

--J. W. Hornbeck
K. G. Reinhart
C. A. Troendle

[1/] Lee, Richard. 1963. Evaporation of solar beam irradiation as a climatic parameter of mountain watersheds. Hydrology Paper 2, Colo. State Univ., Ft. Collins, Colo. 50 pp.

PROJECT 1603 - WATERSHED CORRELATION AND SYNTHESIS

During the first 6-months life of this project we got correlated and synthesized into doing a paper for the ASCE on effects of urbanization on streamflow, a paper for the SAF Allegheny Section on effects of even-aged management (clearcutting) on water, a Station Paper with Ken Reinhart on water yield management on forested watersheds in the Northeast (to go along with our drought), a paper for the Municipal Watershed Symposium that was held in November at the University of Massachusetts, and the promise of a paper for the Departmental Yearbook. In a burst of optimism we worked out a cooperative study with Art Eschner (Syracuse) to pull out, if possible, land-use effects from long-time streamflow records in the East. During the afternoons we read and re-read the Symposium Proceedings, editing lightly, and finally took the 1800 pages to the publisher in February. They promise us a book this year. Besides the care of the manuscripts, we worked up last year's radiation data from our New Jersey study into an office report, spent a day in Washington helping ourselves to Herb Storey's library, and two days with Ron Whipkey and Dave Striffler at our Station's Ohio addition. Finally, the Project lost half its professional help with the departure of our long-time associate Irv Reigner to the Washington Office. When last seen the Project Leader was staring unhappily at item 6c in the line project report.

--Howard W. Lull

PROJECT 1604 - STREAM REGIMEN AND WATER YIELDS

Solar radiation relationships

During the past six months, approximately 4500 measurements have been taken in continuing investigation of the spatial variation of reflected short-wave radiation above a 34-year old pine plantation. Data are recorded on strip chart recorders from Moll-Gorczynski type solarimeters as they pass along cable tramways above the forest canopy. Electric winches move the instruments along the tramways at selected rates. A computer program has been prepared to transform the field data into energy units and reflectivity ratios (albedo).

Reflectivity ratios along a 100-foot tramway at mid-day in July under clear sky conditions ranged from .097 to .117 with a coefficient of variation at 6.3%. Under full cloud cover at mid-day in December, the reflectivity ratio along the same tramway ranged from .076 to .089 with a coefficient of variation at 5.5%.

Of particular interest are the data from February 26 presented below. A snowstorm started the previous afternoon, ending in the early morning hours on the 26th. Total accumulation on the ground was 12 to 14 inches. Approximately 4 inches of snow remained on the canopy at the end of the storm period. The sky was completely overcast during the morning hours, clearing during the late afternoon. Air temperature above the canopy was 24°F at 10:00 a.m. and reached a maximum of 40°F at mid-afternoon. Snow started dropping from the canopy in clumps around noon and some needle and branch drip was noted late in the afternoon. However, a considerable portion of the snow remained on the canopy through late afternoon on the following day, the 27th.

It is interesting to note in the data for the 26th that the reflectivity ratio reached a high of .18 above the snowladen canopy under diffuse radiation conditions of overcast sky and then dropped to .11 as the day progressed with temperature increasing, snow hardening, and sky clearing.

Data from Tramway No. 2
Warrensburg, New York Feb. 26, 1966

Time (EST)	Incoming solar radiation	Reflected solar radiation	Coefficient of variation	Standard deviation
	Langley	Langley	Percent	Langley
1000	.43	.18	5.92	.010
1100	.43	.17	5.86	.010
1200	.53	.18	6.02	.011
1300	.75	.17	9.16	.016
1400	.89	.16	10.98	.017
1500	.69	.13	12.42	.016
1600	.41	.11	16.88	.016
1700	.19	.11	17.45	.036

Hardwood Humus

Our portion of the cooperative humus investigation with project 1603 is nearly complete. A total of 108 humus samples were collected from 36 different forest conditions in the area around Syracuse, New York. Humus reached a maximum depth of 2.3 inches in a well-drained sawtimber stand; the minimum depth, 0.0 inches, was found in a poorly drained pole stand. In several cases, no H layer was present on poorly drained sites.

Watershed evaluation

The Tuscarora Creek Watershed in southwestern New York is being studied in an attempt to determine if agricultural abandonment and subsequent natural and artificial reforestation have had an effect on quantity of streamflow and regimen. This is a fairly large watershed (114 square miles) with a variety of land use and cover types.

Type maps of the area have been prepared from aerial photographs for the years 1938, 1955, and 1964. Cover has been classified as forest, brush and reproduction, grassland, and cultivated. Field plots have been established in the first two cover types to enable us to estimate density and specie composition.

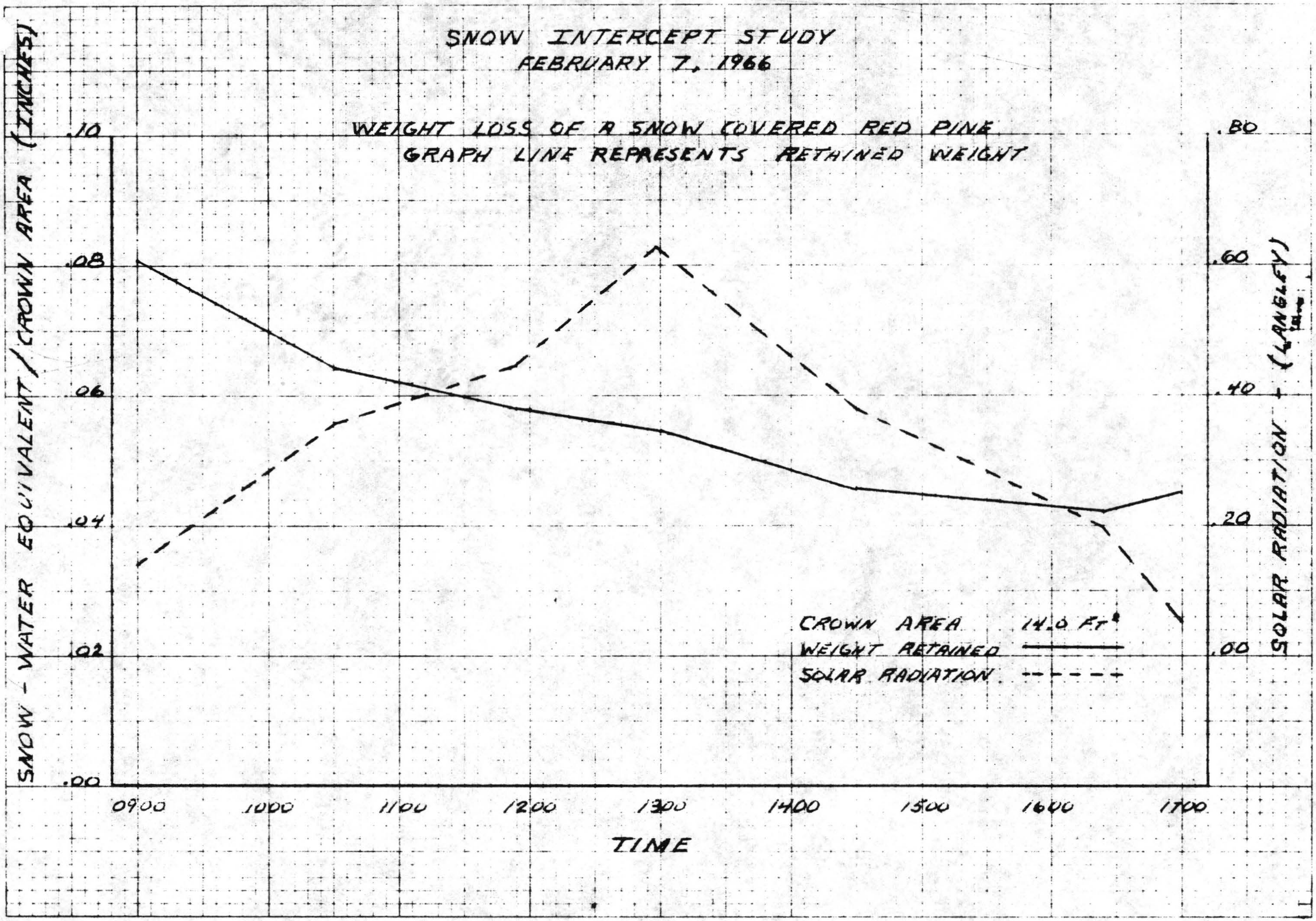
Multiple correlation methods will be applied to runoff and climatic data from the area to determine if changes have occurred in the streamflow pattern and if they can be correlated with changes in cover types.

Snow interception

Three small conifer trees 5 to 6 feet high were mounted on platform scales and weighed at intervals following snowfall to determine moisture held by the canopy and rate of melt of the intercepted snow. A difference of .25 pounds weight or .003 inches depth of water over the crown area was detectable with this system. Generally, the more rapid weight loss occurred in the morning. The rate of loss tapered off in the afternoon and stabilized itself in the late afternoon. A slight weight gain was observed even without visible precipitation. A graph showing this experience along with the measured short-wave solar radiation is presented on the following page.

On February 7, one of the trees held 6.25 pounds of snow, from the previous three days. The minimum temperature during the night was -20°F and the range during observations was +6° to 24°F. The wind was calm during the early and latter parts of the day but increased to a gusty 4 to 6 mph from 1200 to 1630. No snow blew off the sample tree, however, there was a visible loss of snow between measurements. Cloud cover was almost 100% until 1500 hours when the clouds began to break up.

--Ray Leonard


SNOW INTERCEPT STUDY
FEBRUARY 7, 1966
WEIGHT LOSS OF A SNOW COVERED RED PINE
GRAPH LINE REPRESENTS RETAINED WEIGHT
SNOW - WATER EQUIVALENT / CROWN AREA (INCHES)
SOLAR RADIATION - (LANGLEY)
.10
.08
.06
.04
.02
.00
.80
.60
.40
.20
.00
0900
1000
1100
1200
1300
1400
1500
1600
1700
TIME
CROWN AREA 14.0 FT²
WEIGHT RETAINED
SOLAR RADIATION

PROJECT 1605 - FOREST RESTORATION OF STRIP MINED LANDS

The past six months has seen a variety of activity on this project. Probably the biggest item is the change in organizational status. We became part of the Northeastern Forest Experiment Station as of last fall and in the process acquired a new assistant director. The change was accomplished with very little effort. Apart from a new project number, and renumbering our study plans, we have maintained the status quo.

Weldon Weigle, Civil Engineer, resigned the last of February, returning to his home state of Idaho to accept a position with the Farmers Home Administration as State Engineer. Weldon contributed much to the project during his short two-year tour of duty. Needless to say, we are recruiting for a replacement.

Arthur Peterson, Forestry Aid, was caught up in the draft; entering the service in January. Howard McBeath, Physical Science Aid, resigned to accept employment with the University of Kentucky Medical Center.

Inventory of acreage disturbed by strip mining in Eastern Kentucky

Preliminary figures for the strip mine inventory show 49,000 acres disturbed by mining and another 3,700 acres in haulage roads in eastern Kentucky as of September 1, 1964, the cut-off date of the inventory. Approximately 2,5000 acres are being mined annually according to the Division of Reclamation who cooperated in the inventory.

Analysis of partial field data from the characteristic survey shows that 65 percent of the coal seams are covered by backfilling and that 94 percent of the spoil material has a pH between 3.5 and 5.0. Thirty-nine percent of the banks had a 70 percent or better herbaceous cover while only 10 percent of the banks had a 70 percent or better tree or shrub cover. The 70 percent figure represents satisfactory revegetation prescribed by the Kentucky state law on strip mine reclamation.

Field fertilization - 1965

Nitrogen was found to be deficient on most spoil material while phosphorus was deficient on many of them. Thus, the combination of nitrogen and phosphorus is required. Fertilization increased existing cover several fold, with the greatest response occurring on spoils with pH above 5.0. Fertilization must be regarded as a tool in obtaining a quick cover of herbaceous vegetation and is not a panacea that will substitute for timely seeding, non-toxic spoil, or a suitable, stable seedbed.

Plastic access tubes for nuclear probes

One of our research objectives is to study the hydrologic characteristics of spoil bank soils. As part of this we are considering using neutron probes to study moisture and density characteristics of spoil banks. However, we were concerned that conventional aluminum access tubes might not withstand the acid conditions occurring on spoil bank sites. Our next thought was to try plastic tubes as substitutes. A casual survey of the literature turned up little on the subject. Marston had reported testing a number of different materials with the moisture probe in the October 1963 semiannual report. Among the materials tested was a rigid plastic tube of cellulose, acetate, butyrate (CAB). This material looked promising. J. R. McHenry (ARS) used a 2-inch Carlon tubing (material not specified) and experienced a slight count reduction. To satisfy our curiosity, we ran a test similar to Marston's on a locally available PVC (Polyvinyl chloride) and experienced a sharp reduction in count rate. A little study revealed that the count rate is affected by chloride in the tubing. However, we still had hopes and really wanted to use PVC since it is easily available, comparatively inexpensive, and fittings (caps and couplings) are available. We reasoned that perhaps a thinner wall thickness might not suppress the count rate as drastically and might be usable. Accordingly, we obtained samples with different wall thicknesses and some other materials as well. Results are shown in Table 1. As indicated the thinner wall thickness did not reduce the count rate as strongly as the thick, although all the PVC materials reduced the count rate considerably. A test of ABS (acrylonitrile, butadiene, styrene) also gave a sharp reduction in count rate. A test of CAB material agreed quite closely with Marston's test and showed no reduction. The biggest disadvantage with CAB is that standard fittings are not available. It also does not appear to be as rigid as ABS or PVC which might be a disadvantage. We also received samples of an extruded acrylic and polyethelene but both were too small for the probe. We would be interested in hearing if anyone has any experience with plastic access tubes.

A study of water quality from strip mined watersheds

We have been making a survey of strip mining in eastern Kentucky. The primary purpose was to determine the acreage disturbed although a field survey last summer attempted to describe physical and vegetative characteristics of spoil banks as well. Acreage determinations from aerial photographs have been made by counties, on a coal region basis, by geologic province, and for fourth order watersheds. This summer we plan to go a step further and try to relate water quality from the fourth order watersheds to the acreage disturbed by mining, number of underground mines in the watershed, watershed area, discharge, percent of forest cover, and other watershed variables. Water quality determinations will include pH, specific conductance, Eh, and DO in situ; and iron, manganese, sulfate, and potential free acidity in the laboratory.

Table 1.--Subsurface moisture probe (P19) Readings in various kinds of access tubing

Tubing	Outside diameter	Wall thickness	Average Reading Air	Average Reading Water
	Inches	Inches	IPM 1/	IPM 1/
Polyvinylchloride, Schedule 40 (PVC)	1.900	.145	73	11,096
Polyvinylchloride, SDR 26 (PVC)	1.900	.073	70	13,626
Polyvinylchloride, SDR 26 (PVC)	1.660	.064	75	16,765
Aluminum, 6061-T6 Alloy (Marston)	1.625	.035	42	24,652
Cellulose, Acetate, Butyrate (CAB)	1.750	.062	67	23,880
Acrylonitrile, Butadiene, Styrene (ABS)	1.900	.125	77	14,748

1/ Impulses per minute.

Leatherwood Creek

The Leatherwood Creek Watershed is a 2.65 square mile watershed with a complete forest cover and is under one ownership. An estimated 75 percent of the upper perimeter contains coal seams mineable by the contour method. Mining is scheduled to begin in the next year or two. The purpose of this study is to obtain a before and after comparison of streamflow, sediment yield, and water quality from a watershed mined under new state regulations. Because of the size of the drainage and the range of flows anticipated, a tandem gaging installation would probably be ideal. However, since this would run our costs up we have gone to a relatively inexpensive triangular broad crested weir with 1:5 side slopes. This gives us reasonable accuracy at both high and low flows and yet can be replaced by a flume without much loss, if sediment loads become excessive. This is a cooperative study with financial cooperation by the State Department of Natural Resources.

Cooperative Aid Studies

The strip-mined area restoration project is involved in two cooperative aid studies with land grant universities.

Purdue University - Determine cover type utilization by small game in southern Indiana coal stripped lands.

University of Kentucky - Chemical reactions occurring in root zone from oxidation of sulfides exposed in coal strip mining operations.

PROJECT 1606 - MANAGEMENT OF STORM RUNOFF

During the past six months we have been concerned with equipping and shaping a soil and water laboratory, with testing of field and laboratory techniques for determining hydraulic conductivity, with analyzing storm hydrographs (from plots and streamflow), and with study plan revisions.

Hydraulic conductivity (General)

Because of the seeming dearth of knowledge about subsurface stormflow in forest soil, our project has aimed at fundamental study of cause and effect relationships. Past studies have shown us that not all parts of a watershed contribute equal amounts of storm runoff. Little, if any, subsurface stormflow occurred from deep (4-6 feet), coarse-textured soils, while for similar storms and amounts, quick subsurface stormflow did occur from shallow (1.5 to 2.5 feet) soils on the same hillside. One of the causes of this, of course, is the directional hydraulic conductivity of the soil. In finer textured soil, such as a Keene silt loam, this property is greatly affected by the occurrence and amount of subsurface channels caused by tree roots, animals, and structural fissures. Van Dijk has reported a similar observation for hillside soils in Australia (1).

As mentioned in past issues, it is highly doubtful if the hydraulic conductivity of forest soil where interconnected channels are prevalent is the same as that postulated by Henri Darcy in the original work on water movement through sand filter beds.

We sometimes find at this point of a discussion that some workers ask, "How can flow occur through macro-pores and channels if the entire soil mass is not saturated?" The question is valid if the openings are sealed off from the atmosphere. But it must be remembered that air-filled channels and macro-openings serve as a deterrent to flow and reduce the

effective flow area only where these openings are completely closed off (2). Where the openings have access to the atmosphere allowing for ready-exchange of gasses, they serve as minature water sinks and sources. All the surface soils we have investigated are extremely coarse-textured with numerous macro-pores and channels terminating (or beginning) at the surface. (We should reiterate that subsurface stormflow is most important in this area in the period, roughly February through June, and the statements pertaining to flow through soil channels apply only to this period. Little, if any, subsurface stormflow has been observed in the summer or fall seasons.)

Several of our project studies are aimed at determining hydraulic conductivity of permeable forest soils, and in another section of this report Dr. Aubertin describes his initial investigations. We are using both laboratory and field methods. It is felt that laboratory methods using "undisturbed" samples can give an index value of hydraulic conductivity, so that results can be used to compare soil zones or general areas with other of known drainage behavior. But most drainage scientists find that hydraulic conductivity values determined from careful laboratory tests usually do not check results obtained from field tests for the same soils. For example, the hydraulic conductivity of a layered field soil may be appreciably greater in the horizontal plane that in the vertical. Furthermore, thin, interstratified deposits of silt or clay can decrease the effective vertical hydraulic conductivity of a sandy soil while not appreciably changing the average horizontal hydraulic conductivity. Since the core sample is usually a vertical sample, then the laboratory values obtained may or may not fall between the actual horizontal and vertical values for that soil.

There is agreement, however, among the scientists we have consulted that while these laboratory values may not adequately approximate hydraulic conductivity of soil in situ, soil cores are relatively easy and cheap to obtain and the values obtained for an entire profile indicate the critical depths where flow may be rapid, moderate, or impeded. Therefore, we are interested in finding an accurate field method or methods that will give reliable index values for classifying the permeabilities of important forest soils and can be used as standards for comparison with laboratory determinations.

In the early days of this project, we attempted to use two standard engineering field techniques--the piezometer method and the auger hole method. We found neither technique would work in our forest soil--mainly because the necessary water table condition was never present. Even while subsurface stormflow occurred, there was insufficient back-pressure present to give measurable piezometric head in the piezometers. We did test the auger hole method in one small saturated area, but found it difficult to excavate a hole that met the requirements of this technique. The soil was so stony and coarse textured that it was difficult to maintain the geometry of the hole for the side walls soon sloughed with the rapid inflow.

After a period of several years, we have subsequently investigated field methods which do not require a natural water table condition. These have been developed for use in soils where irrigation is a must. Dr. Aubertin has been working with the Bouwer double-tube method and is interested in using a modification of this. We discussed the various techniques with several irrigation researchers at the ASAE Drainage Conference in December and they all suggested that we try the shallow well pump-in test used by the Bureau of Reclamation. This technique has good possibilities of being the method for determining permeability of extremely permeable, coarse-textured forest soil.

For those interested, the technique (3, 4) consists of preparing a small diameter hole above the impermeable soil layer, casing this hole with such material as burlap, well screen, or a gravel liner. A constant head of water is maintained in this well and the rate of water use is determined until a nearly steady state is obtained. If the geometry of the hole is maintained without sealing the sidewalls (most important in fine-textured material), the method has been found to be quite reliable and the results reproducible.

References:

(1) Van Dijk, D. C. Water seepage in relation to soil layering in the Canberra District. C.S.I.R.O. Div. Rep. 5/58, Adelaide, Australia.

(2) Slater, C. S. 1948. The flow of water through soil. Agricultural Engineering, Vol. 29, pp. 119-124.

(3) Boersma, L. 1965. Advances in Agronomy. No. 9, pp. 242-248.

(4) Winger, R. J., Jr. 1965. In-place permeability tests used for subsurface drainage investigations. Bureau of Reclamation Report, Sept. 1965. pp. 1-13.

-- R. Z. Whipkey

Hydraulic conductivity Research and preliminary results

Our initial efforts were spent in developing a method of obtaining large sized, representative soil samples which included the stones, roots, root channels, and "animal" passageways normally found in forested soils.

A steel sampling device utilizing aluminum cylinder inserts was eventually developed and subsequently used to obtain a large number of soil samples for laboratory hydraulic conductivity determinations. Each

soil sample was 6 inches in diameter and up to 18 inches deep. Samples were taken in multiples of 3-inch depths from the soil surface down, and ranged from 0-3 inches to 0-18 inches deep samples.

Contemporary with development of the sampling device, numerous attempts to obtain field measurements of the hydraulic conductivity were made with the original unmodified Bouwer double tube equipment according to published procedures (1, 2, 3, 4).

It soon became apparent that the Bouwer equipment in its original form would not work in our stony, root-filled forest soils. Modifications were made which enhanced the useability of the Bouwer equipment, but unfortunately we have not yet found the complete solution. Because of this we decided to investigate the use of a single tube method for obtaining field hydraulic conductivity measurements. A procedure was developed using an 8-inch diameter tube which was driven into the soil in 3-inch increments. At each 3-inch depth the time-rate of water flow through the inclosed soil sample was determined and the hydraulic conductivity value calculated via the falling head method. A large number of values were obtained before the onset of freezing weather and the data tentatively indicate considerable promise for this method. However, many more values must be obtained and correlations established for this method, the 6-inch diameter samples, and for the long accepted 3-inch core method, before any firm conclusions can be drawn.

We are currently working on equipment and procedures for determining the pore size distribution within the 6-inch diameter soil samples. We anticipate that correlations between the pore size distribution and hydraulic conductivity values should prove very valuable in future characterization of forest soils. It is hoped that by learning more of the pore size distribution-hydraulic conductivity relationship, we will gain valuable leads toward predicting subsurface stormflow from forested watersheds.

The foregoing studies bring up an interesting point which is normally overlooked or not considered by most laboratory investigations. Laboratory determinations of the hydraulic conductivity of each individual soil layer or series of depths may not provide an adequate understanding of the hydraulic conductivity of the entire soil column. In many cases a very inaccurate overall picture may be formulated by considering the individual depths or layers as being indicative of what to expect from the full depth sample. For example the 12-18 inch deep sample may have a hydraulic conductivity value of only one cm/hr while the 0-18 inch deep sample which includes the 12-18 inch sample may have a conductivity ten or more times greater. By taking only the results from the 12-18 inch depth, one might conclude that the low conductivity for this depth would limit or control the conductivity of the entire soil column. But, as pointed out above and from the theoretical calculations of Swartzendruber (6), this is not necessarily the case. The

following table points out the above, verifies Swartzendruber's calculations, and indicates the fallacy of predicting the action of the entire soil column from examination of its parts.

Hydraulic conductivity values obtained from forested Keene silt loam

Sample depths	Average hydraulic conductivity*	Sample depths	Average hydraulic conductivity*	Sample depths	Average hydraulic conductivity	Sample depths	Average hydraulic conductivity*
0- 3"	44.3	0- 6"	56.5	0- 12"	28.5	0- 18"	11.9
3- 6"	29.1	6- 12"	15.3				
6- 9"	18.8	12- 18"	3.0				
9- 12"	10.2						

*Average of at least 10 separate samples.

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